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Assessing boreal forest photosynthetic dynamics through space-borne measurements of greenness, chlorophyll fluorescence and model GPP

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The seasonality of photosynthesis of boreal forests is an essential driver of the terrestrial carbon, water and energy cycles. However, current carbon cycle model results only poorly represent interannual variability and predict very different magnitudes and timings of carbon fluxes between the atmosphere and the land surface (e.g. Jung et al. 2011, Richardson et al. 2012). Reflectance-based satellite measurements, which give an indication of the amount of green biomass on the Earth's surface, have so far been used as input to global carbon cycle simulations, but they have limitations as they are not directly linked to instantaneous photosynthesis. As an alternative, space-borne retrievals of sun-induced chlorophyll fluorescence (SIF) boast the potential to provide a direct indication of the seasonality of boreal forest photosynthetic activity and thus to improve carbon model performances. SIF is a small electromagnetic signal that is re-emitted from the photosystems in the chloroplasts, which results in a direct relationship to photosynthetic efficiency.

In this contribution we examine the seasonality of the boreal forests with three different vegetation parameters, namely greenness, SIF and model simulations of gross primary production (gross carbon flux into the plants by photosynthesis, GPP). We use the enhanced vegetation index (EVI) to represent green biomass. EVI is calculated from NBAR MODIS reflectance measurements (0.05deg, 16 days temporal resolution) for the time from January 2007-May 2013. SIF data originate from GOME-2 measurements on board the MetOp-A satellite in a spatial resolution of 0.5deg for the time from 2007-2011 (Joiner et al. (2013), Köhler et al. (2014)). As a third data source, data-driven GPP model results are used for the time from 2006-2012 with 0.5deg spatial resolution. The method to quantify phenology developed by Gonsamo et al. (2013) is applied to infer the main phenological phases (greenup/onset of activity, maturity, senescence and end of season) from all 3 data streams. Maps of the transition dates (most of all the start of season) of EVI, SIF and GPP are derived and compared. Further, local comparisons of the annual cycle over several large scale regions and forest types are done.

Among other results, we find that in the boreal evergreen needleleaf forests both model GPP and SIF indicate much earlier onset of activity than EVI. This confirms – on a larger scale - findings from tower observations. Moreover, the end of activity occurs later in the case of SIF and GPP, which results in an overall longer growing season. Summer peak values of chlorophyll fluorescence, model GPP and greenness are reached approximately at the time of the annual temperature maximum one month after the illumination peak. In deciduous forests the length of the growing season indicated by the three proxies is very similar, however, SIF and GPP show large intraseasonal variability that cannot be identified using EVI. Also a slight decline in all three proxies can be observed from the end of June until August indicating that greenness and photosynthesis are already reduced to a small extent before autumn senescence starts and before the annual temperature maximum is reached. This might be due to higher sensitivity to illumination than to temperature at that time of year. These and other results show that satellite measurements of chlorophyll fluorescence reliably indicate plant activity and that they might be useful for benchmarking dynamic global vegetation and carbon cycle models.